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**Final Report  
*Strategic Materials***



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# STRATEGIC MATERIALS 2004

**ABSTRACT:** Strategic materials are those materials and related technologies whose critical function or supply are essential to the economic competitiveness and security of the United States. Emerging materials and technologies are key enablers to military transformation and economic growth. The U.S. needs to continue to fund research and development and create an environment conducive to transitioning research to manufactured products. The Buy America policy needs to be reviewed and the waiver process streamlined. A virtual strategic stockpile needs to be created and rare earth elements considered for stockpiling. The government must vigorously enforce the intellectual property rights of U.S. companies.

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# THE STRATEGIC MATERIALS INDUSTRY

## INTRODUCTION

With the end of the Cold War and the beginning of the new millennium, the world has witnessed significant changes in the international security environment. The United States today stands alone as the sole military superpower with no military peer-competitor. In addition to the war on terrorism and continuing military operations in Iraq and Afghanistan, threats to our national security continue to evolve in a world increasingly characterized by complexity, instability, and ambiguity. It is within this environment of instability and ambiguity that the armed forces endeavor to transform into a leaner more agile force, capable of rapidly responding to threats and challenges to national security.

While not a comprehensive study of all materials and technologies, this industry study focuses on several materials and emerging technologies that will play a significant role in ensuring the economic competitiveness and national security of the United States in the next two decades and beyond.

Given the difficulty in defining the boundaries of the *strategic materials* “industry,” our purpose in this report is to present an executive summary of several key materials and technologies in a global context. Specifically, this discussion will: 1) define the industry; 2) evaluate the current condition, challenges, and outlook; 3) assess the industry’s contribution to national security, our nation’s competitive advantage, and transformation efforts; and 4) provide recommendations for Government action.

## Definition and Scope

The Department of Defense defines strategic materials as “Material required for essential uses in a war emergency, the procurement of which in adequate quantity, quality, or time, is sufficiently uncertain, for any reason, to require prior provision of the supply thereof.”<sup>1</sup> While this definition serves the needs of managing the Defense Logistics Agency’s Strategic and Critical Materials Stockpile, it is too narrow for the scope of our industry study.

Materials and technology selection contained representative mature and emerging materials and technologies but was not exhaustive in scope. To structure our exploration of the strategic materials industry, this paper adopts the following definition: “Materials and related technologies whose critical function or supply are essential to the economic competitiveness and security of the United States.” The scope excludes materials used for fuel.

The inclusion of technologies represents the most significant departure from traditional materials study. Many of these technologies use readily available chemical substances or materials. Their strategic value derives from the manufacturing process. For example, carbon nanotubes are manufactured from graphite, which is an abundant non-strategic commodity. The strategic value resides in the technology that can transform this commodity into finished products with strategic value.

## **HISTORY OF STRATEGIC MATERIALS AND THE STRATEGIC AND CRITICAL MATERIALS STOCKPILE**

Strategic materials have been with us since man first picked up a club. Historians have used strategic materials to identify man's history. The Stone Age, Bronze Age, Iron Age and more recently the Steel Age of the 20<sup>th</sup> century define what was considered strategic at the time. Some may even call the later part of the last century the Silicon Age. The only constant is that strategic materials come and go as technology evolves.

The fact that materials do not remain strategic indefinitely poses problems for our strategic and critical materials stockpile. The stockpile was established following the experience of the two world wars. The Strategic and Critical Materials Stockpile Act (50 U.S.C. 98 et seq.) mandated that a stockpile of strategic and critical materials be maintained to decrease dependence upon foreign sources of supply in times of national emergency.<sup>2</sup> The Federal Emergency Management Agency (FEMA) and the General Services Administration (GSA) jointly managed the stockpile until President Reagan issued an Executive Order designating the Secretary of Defense as "Stockpile Manager" in 1988.<sup>3</sup>

The demise of the Soviet Union and the end of the Cold War brought about a significant shift in strategy with respect to maintaining a large stockpile of strategic and critical materials. Since 1994, \$4.33 billion of excess stockpile inventory has been sold, reducing the value of the stockpile to just \$1.7 billion, of which \$1.6 billion has been authorized for sale. However, only three materials are currently required for stockpiling - beryllium metal, quartz, and mica.<sup>4</sup> The reduced reliance on a national strategic and critical materials stockpile recognizes the reality of globalization. The U.S. is wholly or partially dependent upon the global marketplace for many of today's material needs.

## **STRATEGIC MATERIALS TODAY**

Strategic materials play a key role in helping the U.S. fulfill its National Security Strategy. The national vision and commitment to pursue economic growth and prosperity through free global trade serves as a catalyst for domestic industry to deliver innovative breakthroughs in next generation material technologies. Industry currently faces stiff challenges from global competitors that often excel on the strength of their ability to produce well-established material commodities at lower cost. The economic Holy Grail available to U.S. industry is shifting to advanced materials development that promises enormous returns on investment for "first to market" innovations.

Further, material breakthroughs are essential for improved homeland defense and continued U.S. military dominance and transformation. The force envisioned in Joint Vision 2020 must be lighter, faster, and more lethal and survivable. Characteristics of the future force must include dominance of space, network centric operations and warfare, unmanned platforms, stealth, and advanced sensor and communication capabilities. The Global War on Terrorism (GWOT) includes a complex global battle space shaped by urban warfare, concealed and time-critical targets, weapons of mass destruction, and asymmetric threats. This environment will place a premium on the ability to deliver solutions for enhanced individual combatant protection, improved equipment capabilities

and survivability, reduced life cycle costs, and preservation of existing and aging weapon system inventories.<sup>5</sup>

We will begin by exploring the posture for meeting these current and near-term defense needs. Issues with meeting these needs center on access to key materials and the ability to innovate and commercialize new technologies. Here, the issue of access will be examined from a global perspective.

We also examine the ability to respond to large increases in material demand as may be required during a period of mobilization or surge. Although not currently envisioned as a military need, due in large part to the belief that future conflicts will be of short duration, it is important to understand how well we are postured to meet surge requirements resulting from an unexpected short duration conflict or a large scale or protracted conflict.

## **POSTURE FOR MEETING CURRENT AND NEAR-TERM (2015) NATIONAL SECURITY NEEDS**

Strategic materials and technologies can be divided into three broad categories: those materials and technologies that are well established and that contribute significantly to the U.S. national security today, new materials and technologies that have appeared during the last few decades and are playing an increasing role in national security, and those materials and technologies that are now emerging and that hold great promise in fulfilling future requirements. We examine the status of each category with respect to its contribution to defense needs and economic prosperity.

### **Established Materials**

Established materials include steel, aluminum and titanium. Each of these materials has been around for several decades, and their related industries are considered mature. The U.S. is an important consumer of each of these materials.

**Steel.** U.S. steel production accounts for less than 10% of total world production.<sup>6</sup> Over the last several decades, iron and steel production have been steadily moving offshore. Today, the U.S. steel industry produces 103 million tons, down from a peak of 137 million tons in 1973, and is able to meet 80% of U.S. requirements.<sup>7</sup> Fortunately, from a global perspective, the steel industry remains highly competitive and geographically diverse. In addition, international steel companies have consistently shown they can introduce new steel types and new manufacturing techniques into the global market. Global competition had been yielding lower costs and better performance. However, recent increases in the demand for steel by China has caused steel prices to significantly increase, nearly 60% in the last 8 months.<sup>8</sup> China had previously been a net exporter of rolled steel but now is a major importer, consuming more than a third of the world's output of rolled steel, more than the United States and Japan combined.<sup>9</sup> This could lead to other metals such as aluminum replacing steel, should steel prices continue to rise.

**Aluminum.** The U.S. is currently the world's largest consumer and one of the top producers of aluminum. While the U.S. does not have a domestic, economically viable source of bauxite, the raw material required to produce aluminum, bauxite is very abundant on a global basis.<sup>10</sup> In 2002, the U.S. produced about 10% of the world's alumina, which is the intermediate product made from bauxite and is used to produce aluminum. However, its share of global production has slipped from over 30% in the 1970s as Australia, Brazil and other producers have taken on a much larger role.<sup>11</sup> Likewise, U.S. production of aluminum, historically the world's largest, has been declining since the 1970s as foreign production gained a competitive advantage. In recent years, however, U.S. production has declined in absolute terms as high energy costs – by far the greatest cost driver in producing aluminum – have led to the closure of a number of U.S. smelting plants. As a result, imports are playing an increasingly larger role in meeting U.S. requirements, with Canada accounting for 60% of all imports.<sup>12</sup> Given the wide availability of bauxite and alumina, and the forecasts for global aluminum production to keep pace with global demand,<sup>13</sup> we believe that aluminum will continue to be available to meet U.S. national security requirements and economic needs over the next few decades.

**Titanium.** In its raw form, titanium is the fourth most abundant metal in the earth's crust. In its processed form, titanium possesses much sought-after engineering properties: it is strong, lightweight, highly corrosion-resistant, biocompatible and non-magnetic. However, titanium's high cost limits its use to less than 1% of the tonnage of aluminum and less than 0.1% of steel.<sup>14</sup> The U.S. relies heavily on imports of ores, primarily from Australia and South Africa,<sup>15</sup> and of metal from Japan, Russia and Kazakhstan.<sup>16</sup> The aerospace industry consumes approximately 65% of the titanium metal used, while the remaining 35% is used in armor, chemical processing, power generation, marine and other commercial applications.<sup>17</sup> Notwithstanding its reliance on imports, the U.S. remains a leader in titanium technology. The Department of Defense is exploiting and expanding the use of titanium in ground-based weapon systems and naval applications. Several initiatives are in progress, some spearheaded by DoD, to improve titanium's price competitiveness. The key cost reduction strategies focus on improving the extraction technologies and decreasing processing costs. Processing costs can be reduced by using powder metallurgy technology to reduce waste and by seeking new markets to realize economies of scale.

### **New Materials and Technologies**

New materials and technologies are those that have generally been introduced during the last few decades. While production methods and throughput have not yet reached the scale of established materials, new materials are increasingly challenging established materials for market share and contribution to defense requirements.

**Rare Earths.** Rare Earth Element (REE) metals and compounds are produced through the mining and beneficiation of mineral resources containing the 15 lanthanide elements as well as yttrium, scandium, and thorium. REE metals possess superior magnetic, thermal, and electrical properties and their use is widespread across critical



military weapon system applications. Substitution of alternate materials for REEs will nearly always result in significant system redesign and degradation in system performance. REEs have emerged as key enablers driving next generation performance in the electronics, communications, optics, catalyst, and petroleum refining industries. China accounted for 94% of the total global mining production in 2003 and provides most of the U.S. requirements in REEs.<sup>18</sup> Production mining at the Mountain Pass, California, site - the only economically viable domestic source - was suspended in 2003 after years of costly environmental compliance setbacks.<sup>19</sup> Despite its total recent dependence on material imports originating from China, the U.S. maintains a technically advanced but economically modest raw material refinement industry. Global REE resources are sufficient to sustain and fuel expected industry growth well into the 21<sup>st</sup> century. However, the U.S. must be sensitive to the national security risks associated with dependence on a single global, potentially non-friendly, supplier. Even with the expected resumption of operations at Mountain Pass, the U.S. will remain substantially dependent on Chinese neodymium, samarium, and yttrium for certain critical military applications.

**Composites.** Although composite materials are a worldwide industry, the U.S. is generally regarded as a world leader. The 5,350 processing facilities in the U.S. produced \$22 billion in output in 2002.<sup>20</sup> Advanced composites are already extremely important to the defense industry and will be even more critical in the future because they offer the greatest strength and stiffness-to-weight ratio among all engineering materials.<sup>21</sup> Composites are expected to be a key enabler in the development of lighter and more mobile forces. They also offer the simplest route for embedded sensors, actuators and other elements, thus providing much sought after multi-functionality. Revolutionary advances in composites are expected to occur from the use of nanotechnology, wireless technology and self-healing mechanisms.<sup>22</sup> Provided that the cost of manufacturing composites continues to decline, composites could displace steel and aluminum as the primary materials in manufacturing, transportation and construction.

**Advanced ceramics.** The advanced ceramics industry is currently dominated by Japan, which controls approximately 56% of global market share. U.S. market share has been dropping in recent years as foreign firms continue to buy U.S. companies, although some of that capability still physically resides in the U.S. under the name of the foreign firm. Nonetheless, the U.S. remains a leader in the development and use of Ceramic Matrix Composites (CMCs) as well as those ceramics used in high stressing environments driven primarily by DoD and NASA investment. This had led to the use of advanced ceramics in lightweight body armor, aircraft engines, infrared missile domes, and some space applications. Increased future use of ceramics for defense applications is likely, based upon desirable material properties. However, high manufacturing costs and reliability issues currently limit their use. In addition, raw materials, specifically powders for monolithics and fibers for CMCs, require U.S. manufacturers to rely on imports primarily from Japan. Attempts by DoD and NASA to develop domestic sources have not been altogether successful. Overall, increased use of advanced ceramics appears promising if manufacturing costs can be substantially reduced.

**Powder metallurgy.** The powder metallurgy and particulate materials industries enable the manufacturing of components, at modest temperatures, in near net-shape, with mechanical properties that exceed those of wrought metal. Powder metallurgy components are lighter, more durable and corrosion-resistant, have a longer life cycle and are less costly to produce. Different mixtures of alloys can be used to achieve the best possible strength and weight requirements for the components needed. High economic efficiency and environmentally friendly manufacturing processes make powder metallurgy a really forward-looking technology. While growth in the U.S. industry is mostly spurred by the automobile sector, the industry is poised to play an increasingly greater role in defense as the military transforms into a lighter and more agile force. A global abundance of the metal powders and alloys used in the manufacture of components through powder metallurgy should ensure access to these materials for several decades.

### **Emerging materials and technologies**

In this section, we examine materials and technologies that have the potential to revolutionize manufacturing and significantly improve defense capabilities. Some of these materials are commercially available today. Others are showing promise in laboratories or in small-scale production.

**Nanotechnology.** Nanotechnology is the ability to work at the molecular level, atom by atom, to create structures with a fundamentally new molecular structure and exploit novel properties exhibited at the nanoscale. The impact of nanotechnology on products and manufacturing processes promises to be huge. Nanotechnology could represent a \$1 trillion market and generate over 2 million new jobs worldwide, including 800,000 to 900,000 jobs within the U.S., by 2015.<sup>23</sup> The major industries affected will be materials, pharmaceuticals, chemical manufacturing (catalysts), aerospace, tools, healthcare, and electronics. In electronics, carbon-based nanomaterial could potentially replace silicon as the basic building block for chips and circuit boards.

With so much at stake, it is not surprising that, internationally and within the United States, significant investments have been made in nanotechnology R&D. Japan, Western Europe, China, Canada, Australia, Israel, India, Singapore, Mexico and Brazil have collectively invested an estimated \$2 billion.<sup>24</sup> In the U.S., Congress has allocated \$3.7 billion in fiscal year 2003 for the next five years. As of 2003, there were over 230 companies in North America, 80 in Asia, and 120 in Europe engaged in nanotechnology research.<sup>25</sup>

Nanotechnology will significantly enhance the military's capabilities resulting in chemical-biological warfare sensors with improved detection sensitivity and selectivity. Carbon nanotubes are 100 times stronger than steel and 10 times stronger than Kevlar. This will result in stronger and lighter-weight protective armor for the warrior and reduced weight, greater strength and enhanced stealth for platforms and weapons. Lastly, nanotechnology will lead to the miniaturization of platforms from unmanned vehicles to miniature satellites capable of increased endurance and range.

**Microelectromechanical System (MEMS).** MEMS is not a material but a micro-scale system that senses, collects and records information from the environment by measuring mechanical, thermal, chemical, biological, optical and magnetic properties. The U.S. MEMS industry has been growing at a constant rate of approximately 25% annually since 1996, to approximately \$17B in 2002.<sup>26</sup> The market for MEMS is dominated by consumer applications such as sensors used in airbags. RF-MEMS will allow industry and the military to manage inventory and distribution more efficiently. Other MEMS-based systems, such as Micro Air Vehicles and microbotics embedded with MEMS sensors, will increase military surveillance and intelligence capabilities. Biosensors and fluidic lab-on-a chip MEMS will enable faster detection and reporting of hazardous agents. MEMS will allow military systems to miniaturize while enhancing key future capabilities. The entire spectrum of MEMS technology is not yet mature enough to benefit every industry and global competition for greater market share is likely to remain fierce until the arrival of the next miniaturization technology, nanoelectromechanical system (NEMS).

**Smart structures and materials.** Smart structures and materials can sense external stimuli, via internal sensing and/or actuation, and respond with active control to that stimuli in real or near-real time.<sup>27</sup> Today, they are a developing collection of enabling technologies that add capabilities to other manufacturing processes and industries. Many smart technologies are still in the research and development phase, while other applications have been available in industry for years. However, the most promising applications in terms of allowing active control at lower levels of structure<sup>28</sup> are still being tested and are not yet available commercially. Examples of applications for smart materials include sensing systems, vibration control, actuators, self-repairing structures, artificial sphincters<sup>29</sup> and smart fluid dampening of artificial limbs.<sup>30</sup> Developments in these areas are closely linked with other emerging fields, such as nanotechnology and advanced composites. Maintaining a competitive advantage in smart technologies is vital to the U.S. economy as well as the defense industry. Therefore, this area is evaluated and reported upon in the Army Science and Technology Master Plan<sup>31</sup>. The United States and its allies - United Kingdom, France, Germany, and Japan - are clearly in the lead in basic and applied research in this area.

**Biomimetics.** Biological structures and functions mimicked by man are known as biomimetics. It does not consist of a single technology or material, nor is it based on only one scientific discipline. Rather, it is best characterized as an approach for solving a wide spectrum of technical problems. Biology can be mimicked on the macro scale, such as aircraft that mimic the motion of birds, down to the nano scale, such as drug delivery platforms that can move unobstructed within human capillaries. Biomimetics is an emerging field and progress will be greatly supported by advancements in materials science (advanced composites), as well as other emerging technologies (nanotechnology, smart materials). Biomimetics has application to defense (sensor platforms), healthcare (drug delivery systems) and space exploration (autonomous biorobots). Federal funding of basic research programs is currently driving the development of biomimetics. However, it will probably take several decades before biomimetics can contribute

significantly to the U.S. industrial and defense needs. The tools of biomimetics are still being defined and the discipline is confined largely to basic and applied research.

### **Surge Potential**

Lean manufacturing and just in time supply make a surge in materials production nearly impossible. A posture based on no surge capacity can dramatically impact mobilization. The need for surge in some materials became evident during Operation Iraqi Freedom (OIF). The lack of Kevlar delayed the procurement of vital body armor needed by soldiers in Iraq. Dupont, the sole maker of Kevlar, had sized production to meet a stable commercial need with little excess capacity. As a result, it took over a year to meet the Army's urgent needs.<sup>32</sup>

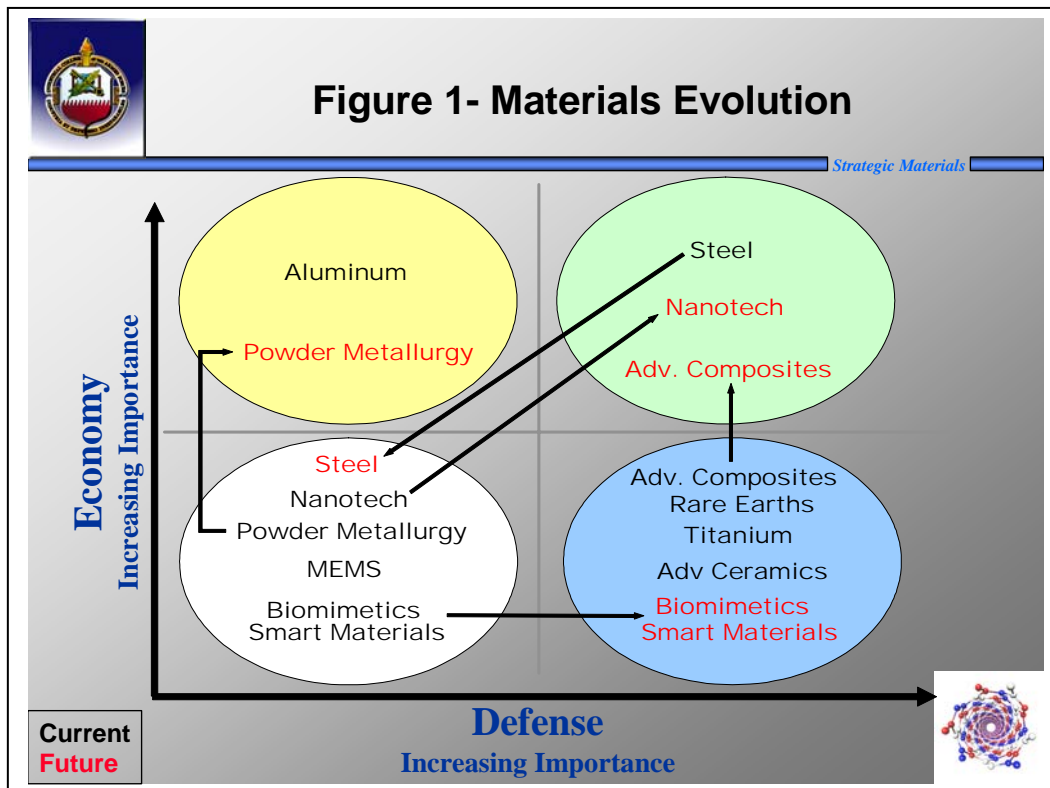
Although substitutions can often be found when a material is not available, the process of requalification can be very time consuming. If this substitution comes from a foreign source, additional time is needed to address "Buy America Act" and "Berry Amendment" requirements. In the body armor case, both of these restrictions effectively nullified the substitution.<sup>33</sup>

### **FUTURE TRENDS, OPPORTUNITIES, AND THREATS**

Research focus, product applications and economic trends vary widely with each sector in the materials industry, depending upon the sector's maturity, user requirements, competition, and many other factors. However, there is a degree of consensus across the research and industrial base that requirements emanating from the transportation, medical, energy, information technology, and environmental industries will create the strongest economic pull for the development of new materials and related technologies in the coming years.

Current and future U.S. military and commercial needs are driving the development of lighter, stronger, more durable, and environmentally friendly materials. A premium is being placed on the development of smart and multifunctional materials that will reduce system life cycle costs while achieving next generation performance. U.S. economic advantage in this era of globalization and manufacturing outsourcing will continue to lie in its ability to outpace international competition in the R&D, patenting, and licensing of new materials and material technologies to achieve product application breakthroughs.

As in other industries, extensive globalization and the rapidly increasing pace of innovation are shaping the competitive environment. Each industry sector seeks incremental improvements or breakthrough materials and technologies to capture an increased market share. The relative importance of the various materials and technologies to both military needs and the overall economy (and U.S. national security in general) continues to change and evolve. Our subjective assessment of the situation that we envisage in 2024 is reflected in Figure 1. We expect that emerging materials will replace the established materials in both defense related applications as well as in their contribution to the overall economy.



Metal sectors such as aluminum and titanium are working hard to reduce material costs in order to create an economically viable alternative to steel in mass consumption product industries such as automobile, aerospace, and appliances. The growing need for lightweight, fuel-efficient transportation is creating a condition favorable for aluminum and titanium to encroach on established steel product markets. A notable example of this trend was seen in the automobile industry. Here, Jaguar has made a strategic decision to introduce the all aluminum XJ model in 2003.

Advancements in powder metallurgy technology allow products previously produced by costly milling processes to be injection molded and pressed to a near net shape product. This technology dramatically reduces scrap, thereby lowering production costs. This may significantly advance the use of titanium as a substitute for steel in many applications.

Meanwhile, the metal sectors now face growing competition from an increasingly innovative composite material sector. The ability to achieve improved product performance and to tailor material properties to individual applications, at increasingly reduced cost, is leading to the increased use of composites in such applications as shipbuilding, aircraft, and land combat vehicles. For example, Boeing's new 7E7 commercial aircraft will use composites for the majority of its primary structure to include the wings and fuselage.<sup>34</sup> In the U.S., the biggest growth opportunities for composites are in infrastructure and energy applications. However, civil engineers will need to accept composites as a structural material for this to happen. Additionally, composite use in housing applications will require changes to building codes.<sup>35</sup>

Rare earth elements and ceramic materials are enabling product breakthroughs and applications that could never be achieved with traditional metals and composites. While these materials may never achieve widespread use in mass produced goods, or make a large impact on the overall economy, their unique thermal, magnetic, and electrical properties are propelling next generation performance in selective applications.

A notable example is the use of ceramics in aircraft engine turbine blades, due to the material's high temperature resistance.

Rare earth elements are emerging as the seminal material ingredient propelling small battery, permanent magnet, color display, catalyst, and military sensor applications that are revolutionizing the communications, electronics, and military weapons markets. With exception to China's current dominance in the production and export of rare earth bearing mineral ores, the natural resources needed to produce and manufacture traditional metals, composites, and ceramics are expected to remain widely available either domestically or from the global market.

In the longer term, emerging materials and technologies have the potential to revolutionize our society and contribute significantly to military transformation. These include nanotechnology, MEMS, smart materials and biomimetics. They require the continued breakdown of traditional boundaries between physics, chemistry, material science, biology, engineering and medical disciplines to deliver revolutionary new products and applications. Continued advancements in these areas are likely to revolutionize the electronics, energy, chemical, and pharmaceutical product industries. Domestic breakthroughs in the development of these emerging materials and technologies can significantly advance U.S. economic well-being. However, the U.S. does not stand alone in the appreciation of the economic potential offered by these materials and technologies. The international race to make technological breakthroughs in these areas is nothing less than a modern day gold rush.

The scale of government, industry and academic R&D focus and fiscal investment is growing dramatically in many countries. However, the national strategies and business models being applied to drive the innovation and transition of basic research discoveries through applied research and ultimately to "first to market" product applications will be keys to capturing global economic market share. It is apparent that the U.S. and its European competitors are taking decidedly different approaches in this effort.

The U.S. Government's investment in advanced materials R&D is significant and currently outpaces international competitors in Europe and the Pacific Rim. The DoD investment in basic and applied research and advanced development across the service laboratories, universities, and industry exceeded \$10 billion in FY-04.<sup>36</sup> Government-funded Small Business Innovative Research (SBIR) contracts with industry and the National Nanotechnology Initiative (NNI) represent significant sources of federal contributions to the development of future materials and technologies.

The trend in domestic industry research spending reflects greater involvement by academic-led small business start-ups with strong ties to university research centers as opposed to the large manufacturing corporations. These same small firms are also producing the greatest volume of technical breakthroughs, which are in turn licensed to the larger and often multi-national manufacturing corporations for scaled-up production.

A trend towards greater collaboration across government, academia, and industry is also observable in the development of new and emerging material technologies. Specifically, university-based Centers of Excellence (COE) are emerging to more tightly couple the strategic needs of military research laboratories with the research focus occurring between university and industry partnerships. Because many advanced material breakthroughs are expected to offer multifunctional properties and applications, the COE concept seeks to break down traditional single discipline material research

paradigms by fostering and focusing multidisciplinary collaboration between project teams of physicists, chemists, material scientists, biologists, and engineers within a common laboratory and research facility setting. The free flow of information and knowledge inherent in the COE construct is intended to serve as a force multiplier for material development and rapid transition to product applications. The University of Delaware Center for Composite Materials and the Massachusetts Institute of Technology (MIT) Institute for Soldier Nanotechnology are premier examples of the COE constructs in action.

Foreign competitors in the global materials industry are taking decidedly different approaches to the development of new materials. Of particular interest is the direct involvement taken by the governments of France and the United Kingdom (UK). Similar to the challenge observed in the U.S industry, European governments and their respective material research and industry sectors recognize the need to reduce the cycle time and efficiency of transitioning basic research breakthroughs to product applications.

The French model intends to take the COE construct to another level by co-locating its entire government material R&D facilities base, its leading material research university, and material application industry groups in the city of Grenoble. In comparison to the U.S. Silicon Valley, the Grenoble model intends to create an industrial research park that will service the entire continuum of basic and applied material research and product application development. In France, research teams that make promising material breakthroughs are given government support to create spin-off companies to transition technology to production.

The UK has taken steps to privatize its R&D laboratories to achieve lower costs and better results through fostering competition. They have recently transitioned 80% of their Defense Science and Technology Laboratory to a public-private spin-off partnership. Similar to the French approach, the UK Ministry of Defense (MoD) will fund the private company for four years after which time it will convert to an exclusively private enterprise. While the private company will continue to support MoD needs, its long-term survival will require that it achieve commercial market breakthroughs.

## **GOVERNMENT AND INDUSTRY CHALLENGES**

The biggest challenge for government is how to encourage invention and innovation so that we can maintain our leadership in the new materials and technologies that are expected to revolutionize many industries and provide huge, lucrative markets. The old paradigm was for government to fund DoD labs and academia. Both of them, in turn, worked closely with big business. It was big business, with its own internal R&D facilities that provided much of the discovery and invention. Today, however, big business no longer plays that role. As a recent article in The Economist noted and our experience confirmed, small business, often located near universities, have assumed the role of inventing new products while big business now limits its R&D to existing product innovation. Since large firms are no longer investing in new inventions and smaller firms have limited resources, government R&D funds are more essential than ever to maintaining global leadership for new products.

Another challenge is how to streamline the process from basic research to manufactured products. Tomorrow's multifunctional products will require a

multidisciplinary approach to R&D. Government needs to be an enabler of the process that will move basic research to applied research to development and ultimately to manufacture products. This process currently takes too long and many good ideas never reach manufacturing due to lack of funding or the right talent at the right time to take the basic or applied research to the next level.

The two biggest challenges to industry in the global environment are conforming to government trade regulations and protecting intellectual property rights overseas. Globalization allows resources and knowledge to move more freely and rapidly across country borders. It has led to greater economic opportunities as well as more competition. The U.S. government defends itself by means of “Buy America” restrictions to safeguard losses of U.S. technology and business to foreign competitors, and uses International Traffic in Arms Regulations (ITAR) to prevent proliferation of materials and technologies critical to our national defense.

Several companies we visited voiced concerns about the application of these protective policies. Although “Buy America” and ITAR are aimed to protect U.S. interests, the U.S. must reassess their validity and effectiveness in the modern globalized environment. A good example of the unintended consequences of Buy America legislation was the surge of woven aramid fabric, manufactured by Dupont under the trade name Kevlar, required during Operation Iraqi Freedom. Dupont, the sole source of Kevlar in the U.S., was unable to surge production capacity to meet the increased demand. Alternate sources were available from South Korea, at one-sixth the cost of the U.S. manufactured items, but DoD was not able to purchase them due to “Buy America” restrictions. The waiver process was so slow that, ultimately, DoD had to wait the year for Dupont to produce them. The result was that U.S. soldiers did not have the protective equipment when needed. A similar problem existed with body armor.

Another serious challenge to the industry is protecting U.S. intellectual property from foreign infringement. Being the first to market new breakthrough products gives a company the potential for global market dominance, and the competition to reach that goal is fierce. Many companies we visited considered the existing international intellectual property protection laws ineffective, as the enforcement process cannot keep pace with the speed of the globalized world. Consequently, some U.S. companies forego the international market and the potential profits rather than risk losing their intellectual property rights overseas. This certainly dampens the U.S. ability to maintain technological and economic advantage. This is especially true with small companies that can’t afford the international legal battle to protect themselves from infringement.

A final challenge deals with our Strategic and Critical Materials Stockpile. In our view, the current sell-off of the stockpile has risks not envisioned in 1993 when the decision was made. In addition to the very real possibility of terrorist sabotage of key production facilities, the emergence of China as a regional hegemon is increasingly possible. In addition, although estimated by DoD as low risk, extended conflicts over future failed states or Korea could emerge.

Given the expense, environmental hazards and inability to keep pace with new material changes, another round of stockpiling may not be useful, except in the case of rare earth elements where China has a monopoly. The government needs to develop a creative solution that better balances the risks and future possibilities.



## **Government's Role and Recommendations**

Material sciences and associated technologies continue to rapidly advance. While entrepreneurship, the free flow of ideas, and open markets promote innovation, the government plays a crucial role in maintaining our strategic readiness. In addition to traditional government functions of regulation and promotion of general economic health, we recommend the U.S. Government take action in the areas of research and development, technology transition, defense acquisition, and stockpile management to sustain our strategic position into the future.

## **Research and Development (R&D)**

R&D fuels improvements in traditional and new materials as well as breakthrough innovations with respect to emerging materials and technologies. The existence of a significant potential commercial market will drive R&D funding by the commercial sector. An example would be a material improvement with application to the semiconductor industry. However, where breakthroughs or improvements would greatly benefit military applications, or where no commercial market exists, government R&D funding is both appropriate and important to ensure future U.S. technological advantage. With respect to the advancement of material sciences, government R&D funding is the key driver. Therefore, we recommend that the government continue to provide adequate levels of R&D funding to fuel innovation and economic growth, despite the significant budgetary constraints that we will undoubtedly encounter in coming years. The potential return on investment makes R&D funding a wise decision, even in tough budget times.

One way that the U.S. Government fosters innovation is by funding the Small Business Innovation Research (SBIR) program. Small businesses have historically provided, and will continue to provide, a significant portion of this country's innovation. Our seminar visited two small companies – one producing titanium powder metallurgy products, and the other producing ceramic matrix composite products – where SBIR funding was instrumental to their success. Dual-use products and technologies were developed which benefited both the public and the private sectors. In one case, it resulted in the creation of an entirely new spin-off company. The SBIR program, when effectively utilized, is a powerful tool that helps create and leverage small business innovation.

## **Technology Transition: From the Laboratory to the Factory Floor**

As previously discussed, successfully transitioning technology from the laboratory to full-scale production is a key challenge to introducing new materials. In many cases, promising materials and technologies don't result in an actual product. The fact that a material or technology is proven to be possible does not mean that it is suitable for profitable large-scale commercial production or for affordable military production.

The chances of successfully transitioning technology from the laboratory to production are greatly improved when traditional "stovepipes" are broken down. Our seminar discovered the effectiveness of a new model – one where customers, basic researchers, applied researchers, and industrial partners work closely together in an

atmosphere of collaboration to create material solutions to identified requirements. In many cases, “researchers” included government engineers and scientists working closely with those from academia (faculty and students). This new model is known as a “Center of Excellence.”

One such Center of Excellence we visited was the Composites Center at the University of Delaware, which was working closely with the customer - the nearby Army Research Laboratory (ARL) - and selected industrial partners, to develop new and/or improved weapons systems, armor, and other products for the soldier. Within the University itself, a highly interdisciplinary approach was utilized as university staff, doctoral students, and post-doctoral students in various engineering disciplines worked together to advance scientific knowledge and achieve solutions to real problems.

The key to achieving innovation through a Center of Excellence is fostering an atmosphere of true collaboration. We saw various methods to do this, ranging from pizza get-togethers for students at the University of Delaware to the French government’s approach of building new facilities for the purpose of physically co-locating all involved personnel. Their site, when completed, will include office space for lease to industrial partners, government laboratories, and an engineering school.

Based upon our observations, the Center of Excellence model, utilizing as much co-location as possible, is the most effective way to improve scientific knowledge and solve real problems. We therefore recommend that the Government continue to help establish and fund Centers of Excellence and consider the creation of new ones where appropriate.

## **Globalization**

To remain a world leader in materials and enabling technologies, the U.S. must protect the intellectual property associated with advances in materials. Some U.S. firms we visited were very concerned about the protection of intellectual property, particularly when selling or collaborating abroad. An atmosphere of assured protection of intellectual property is essential if U.S. companies are to freely trade in a global environment. We recommend strong government support for the enforcement of intellectual property rights abroad. It will be essential for the Government to fully employ diplomatic, economic and informational elements of national power to help ensure compliance with intellectual property laws internationally.

The “Buy America” laws are designed to protect U.S. companies and industries. However, these laws can, under some circumstances, hinder military readiness. We believe that constructive modifications to “Buy America” laws are needed to ensure that military requirements for raw materials can be met in times of national emergency, while still protecting domestic companies and industries. At a minimum, we recommend that this include streamlining and/or relaxing the waiver process.

We also heard from foreign and domestic manufacturers that ITAR is hampering efforts of U.S. manufacturers to expand into foreign markets. ITAR requires that foreign manufacturers apply for ITAR permits when transferring ITAR-controlled items, acquired from the U.S., to their subsidiaries or partners located in another country. The added time and effort are costing foreign manufacturers who threaten to seek out alternate sources, to the detriment of U.S. manufacturers. As already discussed, a healthy

global market is essential for the U.S. competitiveness and leadership in strategic materials. Consequently, our group recommends that the ITAR be reviewed to reflect the global dimensions of manufacturing.

### **National Stockpile**

Managing the national stockpile is a risk-based exercise. Recent events indicate that the U.S. policy toward armed conflict is to minimize conflict length to weeks or months, not years. The current decision to sell off the stockpile (retaining only beryllium, quartz, and mica) aligns with the expectation of only short duration conflicts in the future. Risk is minimized by the retention of short-term supplies of materials and the short-term availability of materials from multiple sources on the global market. A secondary consideration against maintaining an aging physical stockpile is the health of the environment. Our aging stockpiles pose air and water quality concerns, and environmental remediation is expensive. Decreasing the national stockpile, therefore, may present opportunities for environmental improvement. Therefore, in our current post Cold-War environment, we recommend that the government continue to sell off our aging physical stockpile.

We believe, however, that the elimination or significant reduction of the stockpile increases risk in the event of a protracted war or terrorist sabotage of key production sites. Prudent planning can help mitigate some of the risk. We recommend that the Government establish a “virtual stockpile,” whereby a comprehensive list of substitutes for strategic materials can be identified and surged capabilities ensured. To enable surge production capacity, we believe the virtual stockpile should include CRAF<sup>37</sup>-like agreements with domestic sources and formal agreements with foreign sources. The virtual stockpile plan should be reviewed periodically and adjusted according to global conditions. Additionally, the “virtual stockpile” plan should be exercised so as to test the reliability of obtaining materials under surge demand.

Actual stockpiling should be constrained to areas where few sources exist. For example, some Rare Earth Elements, critical in defense applications, are currently available only from China. Prolonged dependence on a single foreign source poses a degree of national security risk that varies with the existing relationship with each source country. Japan recently announced a plan to stockpile particular rare metals, including Rare Earth Elements, to prevent undesired interruptions in their supply chain.<sup>38</sup> Following the Japanese example, we recommend that the government consider the stockpiling of selected Rare Earth Elements (neodymium, samarium, and yttrium) to ensure a steady U.S. supply without total dependence upon China.

### **ESSAY**

#### **Nanotechnology Safety And Environmental Concerns**

A significant consideration associated with any new technology is to ensure that the development is conducted keeping safety of both the public and the environment in mind.

Passage of the 21<sup>st</sup> Century Nanotechnology Research and Development Act was held up in Congress as they debated the need for an ethics center to study societal and ethical issues. There was concern that such a center would hinder the emerging industry's progress, although some Congressmen felt that such a center would ensure objectivity and substance.<sup>39</sup> In the end, Congress did not mandate the ethics center. However, if this developing technology is not ethically managed, it could go the way of genetically modified food. With a potential \$1 trillion global industry, 2 million jobs worldwide and 800,000 – 900,000 jobs in the U.S. at stake, the nanotechnology industry does not need the “Frankenfood” stigma.

Materials at the nano level act quite differently from the macro level or even from the atomic level. While these differences are the very reason that scientists think nano products will be able to revolutionize industries, with the nanocomputer being but an example, these differences are also cause for some concern. Gold, for example, is an extremely inert metal. On the nanoscale however, gold becomes extremely reactive, with the potential to disrupt biological pathways.<sup>40</sup> Carbon nanotubes, which form the most useful nano development to date, were the subject of a toxicology study that appeared in the January issue of the Journal of Toxicological Sciences. The study showed that carbon nanotubes inside the lungs of mice caused lung granulomas - abnormalities that interfere with oxygen absorption and can progress to lung cancer.<sup>41</sup>

Another study conducted at Dupont involved similar exposure in rats. In a surprising result, 15% of the rats with the highest doses died from lung blockages within 24 hours, an outcome not seen from any lung toxin. All the surviving rats developed lung granulomas, just as the mice in the previous study did.<sup>42</sup>

Additionally, it was discovered that the carbon nanotubes do not only stay in the lungs but can work their way into the throat and brain, apparently through the nasal cavity and olfactory bulb. There are scientists who also question whether carbon nanotubes can cause brain disease once in the brain and whether they can cross the placenta into the unborn fetus.

The conclusion is that the carbon nanotubes act much differently in the body than do other carbon-based ultra fine particles. While further research and experimentation are needed to determine the full effects of carbon nanotubes on the body, the nanotubes are being produced now and prudent precautions for workers must be put in place in order to prevent problems from occurring. Since carbon nanotubes act differently than other, larger carbon based structures, the standards will also have to be different. Using a medical mask or even a respirator may not provide adequate protection from airborne carbon nanotubes. Some nanotube factories are submitting their material safety data sheets for carbon nanotubes using the same standards as for graphite.<sup>43</sup> Even some government and university labs do not provide more than dust masks for their nanotubes workers. Our travels confirmed that there is no consistency on the personnel safety procedures for nanomaterial workers. We saw everything from dust masks to full “moon suits.” Clearly, researchers and industry are unsure as to the proper precautions to be taken. Consistent with the history of new and potentially hazardous materials, the safety standards tend to evolve over time as we discover more about the materials in question.

In July 2003 Greenpeace published a report on nanotech and artificial intelligence called *Future Technologies, Today's Choices*. The Greenpeace report warns that a failure to accommodate ethical issues could undermine any social mandate for nanotechnology:

“Although an externally imposed moratorium seems both unpractical and probably damaging at present, industry may find such a fate virtually self-imposed if they do not take the issue of public acceptance seriously.”<sup>44</sup>

Based on what we presently know about the properties of carbon nanotubes and how different they are from those of graphite, the safety issues for carbon nanotubes would also be different than those for graphite. Government and industry need to be smart about this new technology so that the mistakes of the past, the problems that have plagued the asbestos industry, for example, are not repeated.

Written by Captain Michael L. Seifert, USN

## **CONCLUSIONS**

First, although only a small percentage of our GDP, the materials we examined are essential to many other industries thereby resulting in a large collective contribution to GDP. Materials will be key to our future economy. They are also vital to meeting the security needs of an agile, lightweight force combating new threats in a global war on terrorism.

Second, in our judgment, the U.S. materials sector is fairly healthy both from a research perspective and an industry perspective. Global competition is definitely intense. We saw world-class operations in France, Germany, Austria, and the UK. Most companies (foreign and domestic) told us that Government funding was critical for R&D to flourish.

Third, technology transition from the laboratory and university to industry remains a significant challenge. Europe appears to be attempting to closely link government and industry with differing degrees of Public-Private Partnerships. Although we don't recommend this approach, we believe the U.S. government must take more proactive steps to keep U.S. industries competitive, including funding focused on the transition of new materials to manufacturing and proactively setting up Centers of Excellence.

Fourth, since most new, cutting edge innovations will involve small businesses, Government needs to continue funding the SBIR program. This will enable small businesses to remain an integral player in material and product innovation. Government must also vigorously enforce the intellectual property rights of U.S. companies within existing international forums so that businesses, especially small businesses, are not afraid to enter overseas markets.

Fifth, the provisions of the “Buy America” legislation need to be reviewed so that the unintended consequences of this legislation will not have an adverse effect on our military forces. As a minimum, the waiver procedures must be streamlined, especially in times of national emergency.

Finally, we believe the U.S. should continue selling off the existing stockpile and take steps to pursue a virtual stockpile as a hedge against terrorist threats and protracted military operations. This virtual stockpile would contain a mixture of alternative sources, substitute materials, formal agreements with foreign sources, and CRAF-like

agreements for surge capability as well as a small actual stockpile of rare earths (until suitable alternative materials can be found) in addition to the three items remaining from the stockpile sell off.

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